An All-Clear Space Weather Forecasting System Based on Near Real Time Magnetograms

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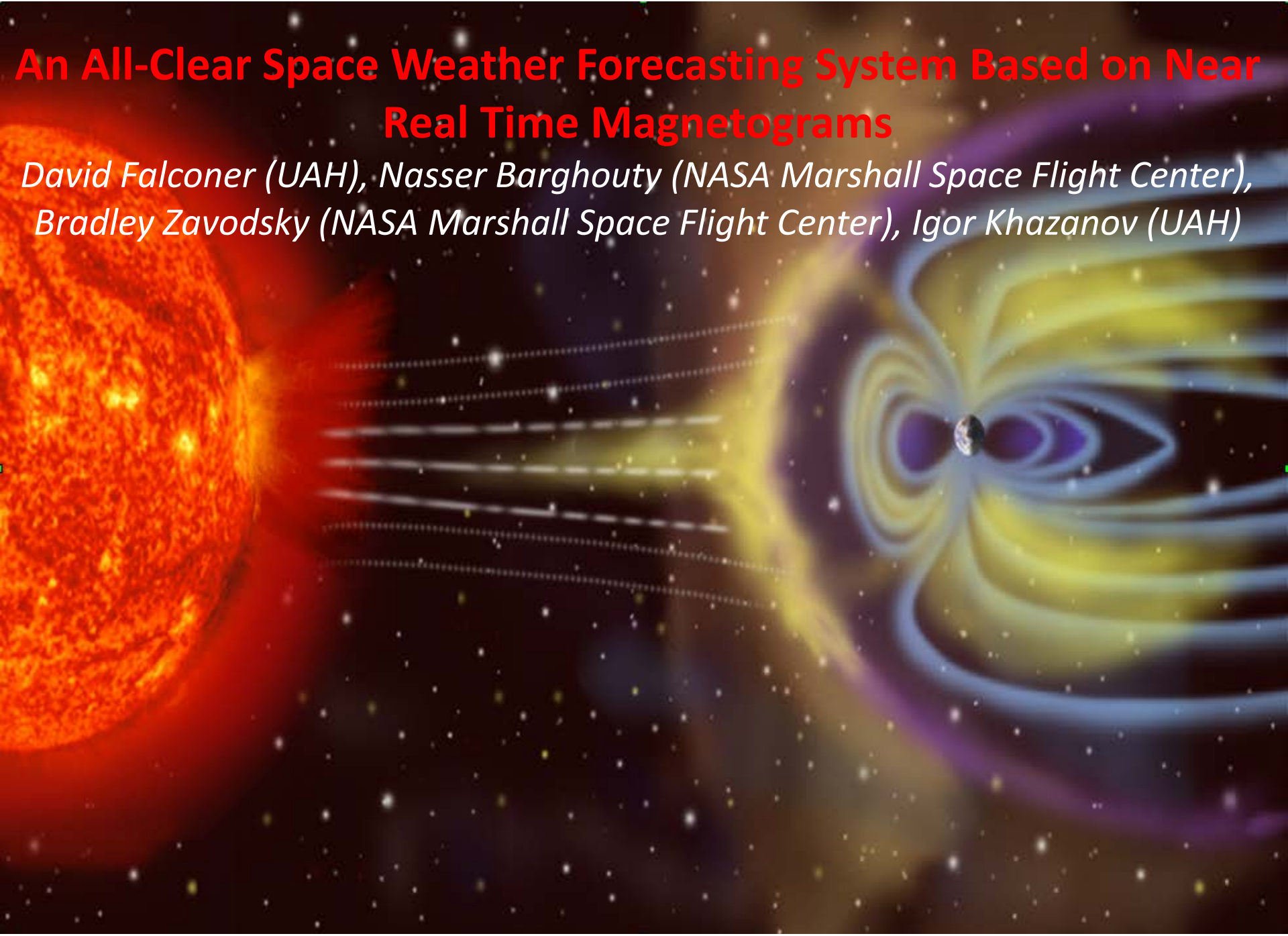
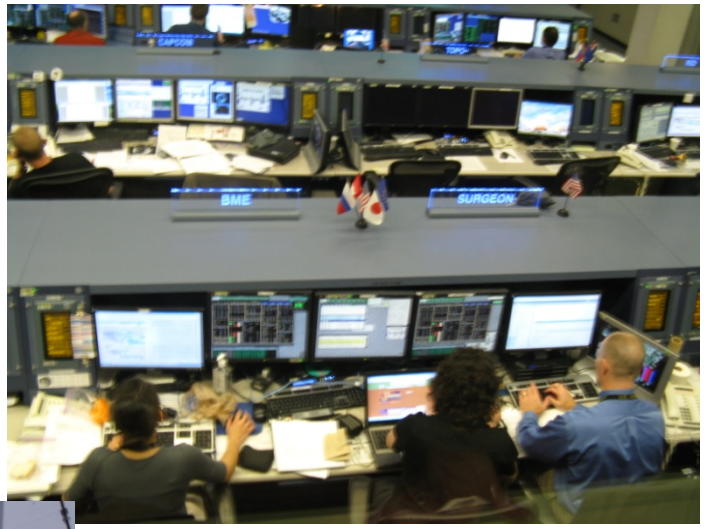


Human Space Flight

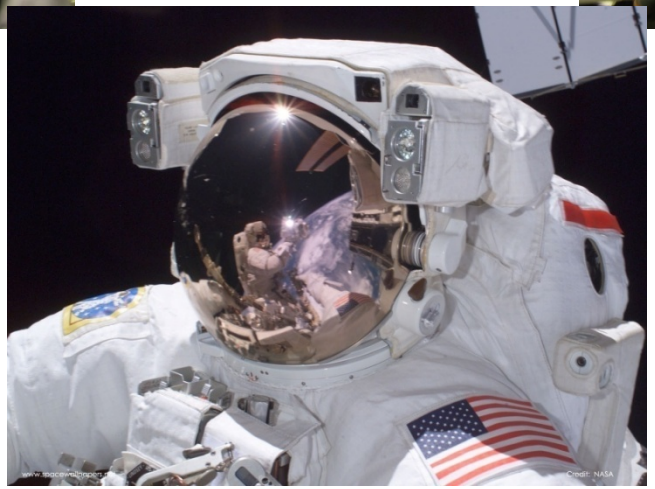
Shuttle missions and Extra-Vehicular Activity require particular attention. The Space Radiation Analysis Group (SRAG) continuously monitors space weather and reports to the Flight Surgeon, if there is a problem or if there is a likelihood of a problem.

SRAG

EVA

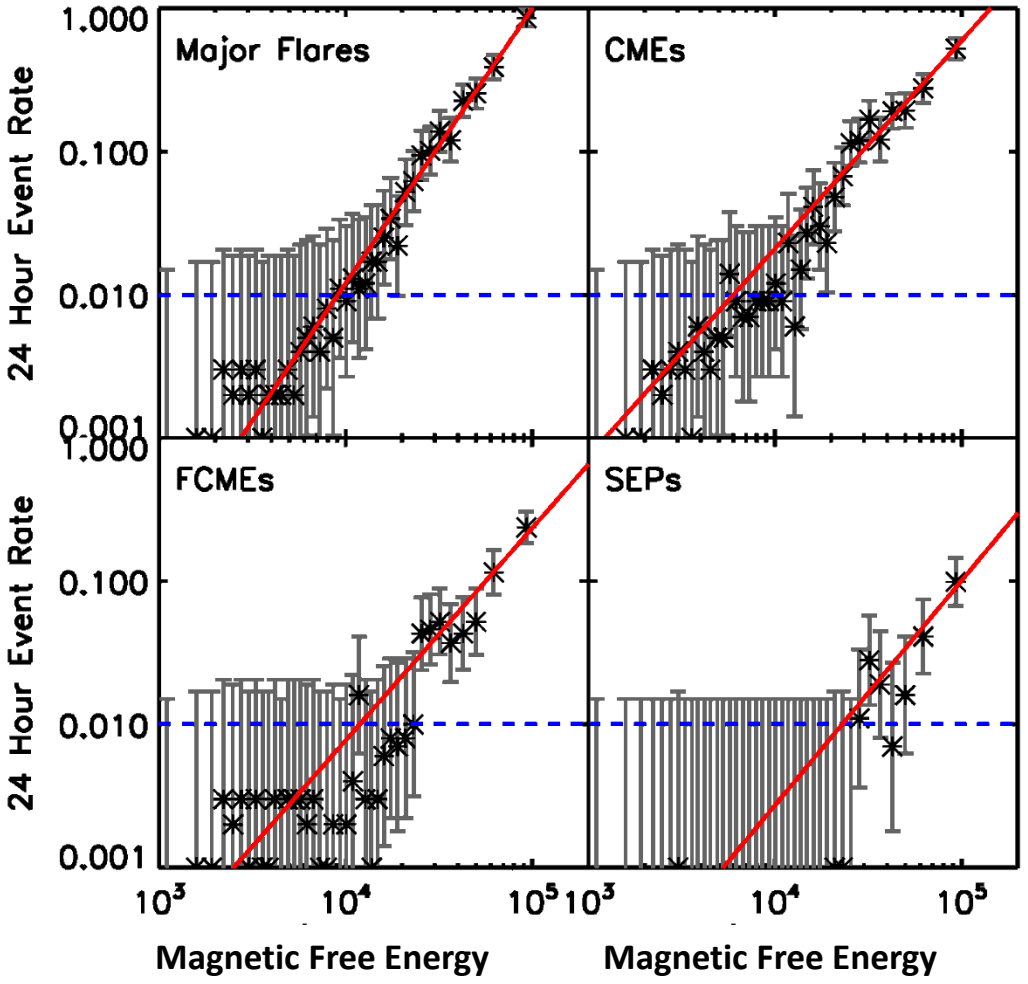


Mission Control

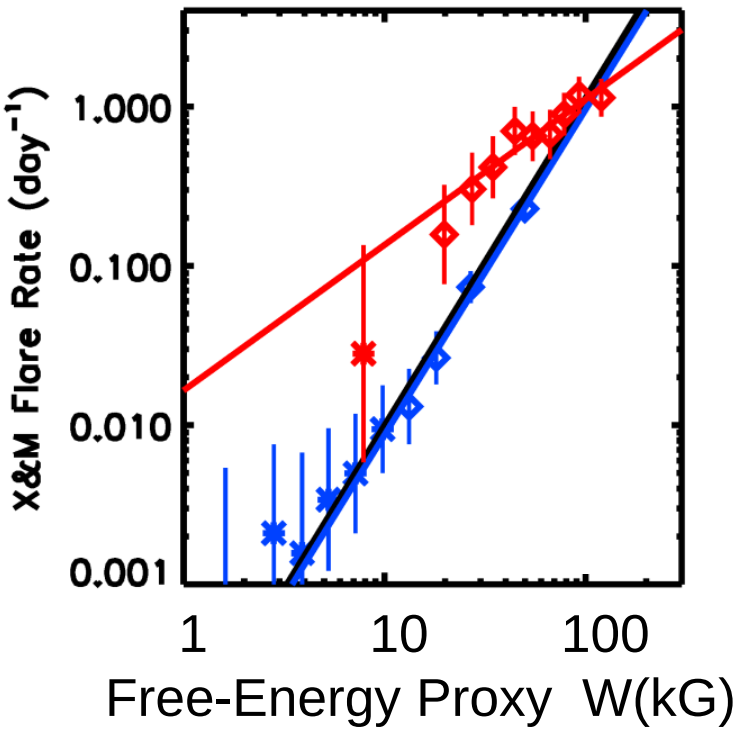


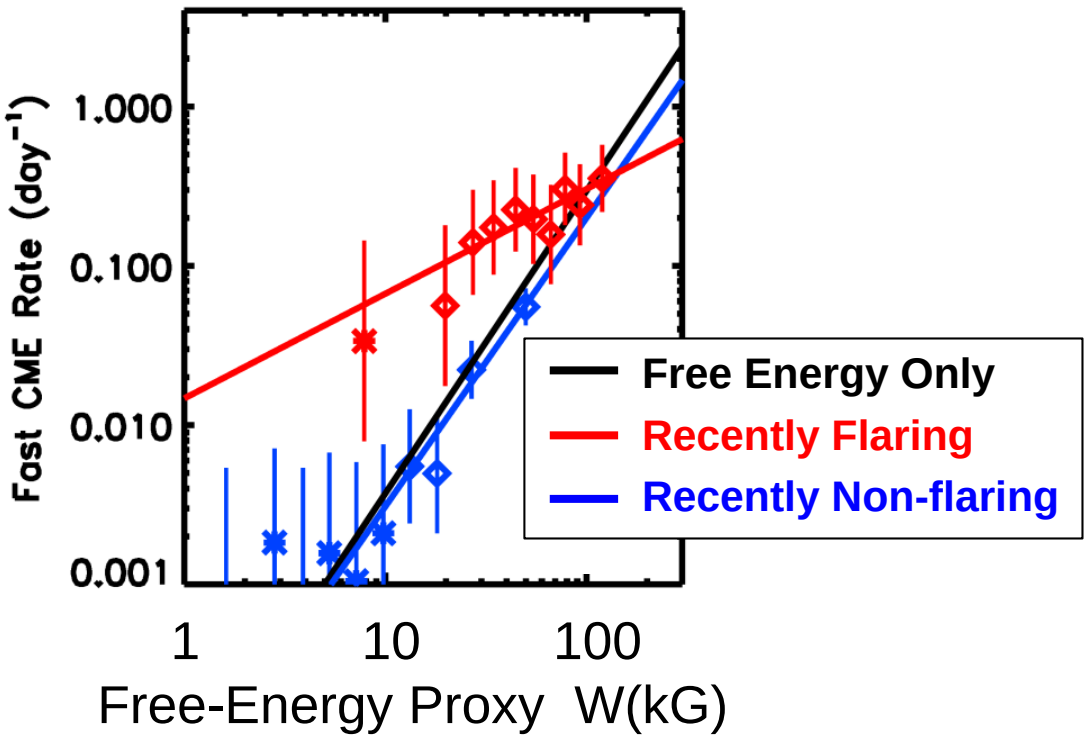
Space Weather Forecasting Curves

- Have found a power-law relationship between our gauge of the free magnetic energy and event rate.
- This occurs for major flares, CMEs, Fast CMEs, and Solar Energetic Particle Events.
- By using this relationship, we can forecast the chance that an event, will be produced by a newly observed active region for which the free energy gauge is measured. (This method is like that for forecasting the chance of rain tomorrow.)



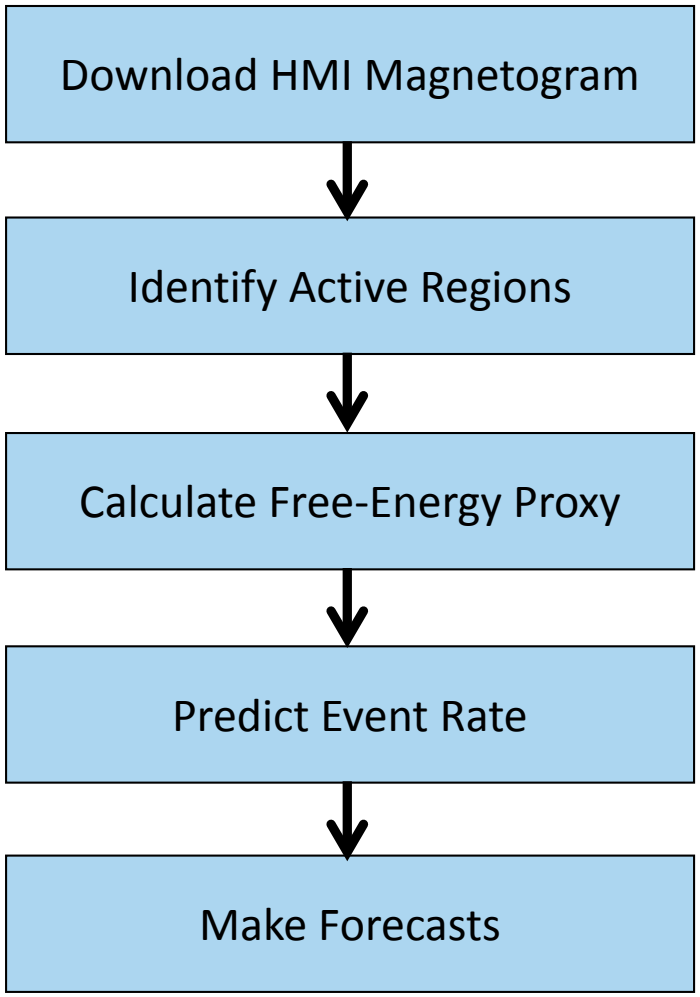
Forecast Curves





Active regions that have recently produced an X- or M-Class flare are more likely to produce flares in the near future

MAG4 Automated Processes



MAG4 is completely automated, from downloading magnetograms to outputting and storing forecast products

Forecasts are probability

Not Time and Magnitude!

Comparison of Safe and Not Safe Days

June 26, 2013

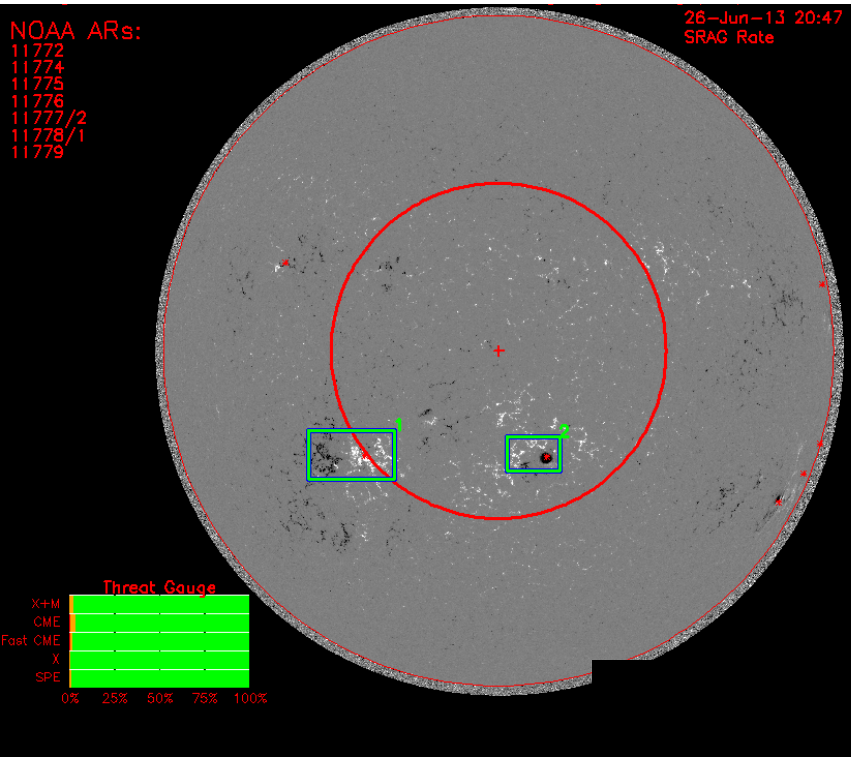
C1, C1.5 flares

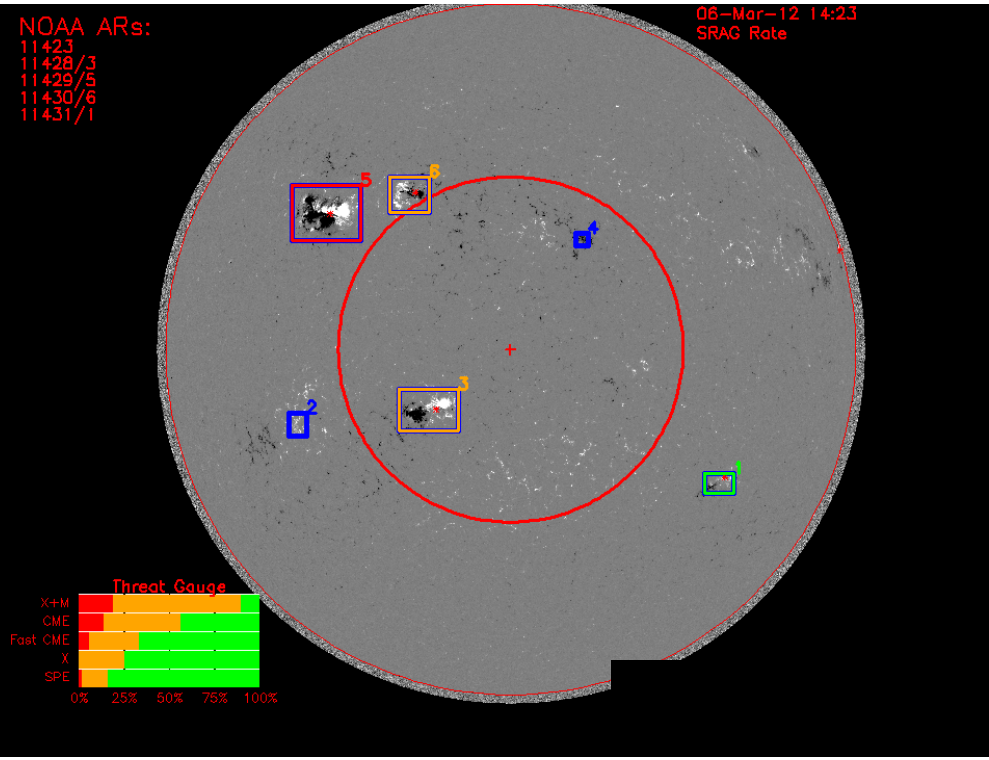
March 7, 2012

X5.4, X1.3, C1.6

CME 2684, 1825 km/sec,

Solar Energetic Proton Event reaches 6530 particle flux unit >10MeV

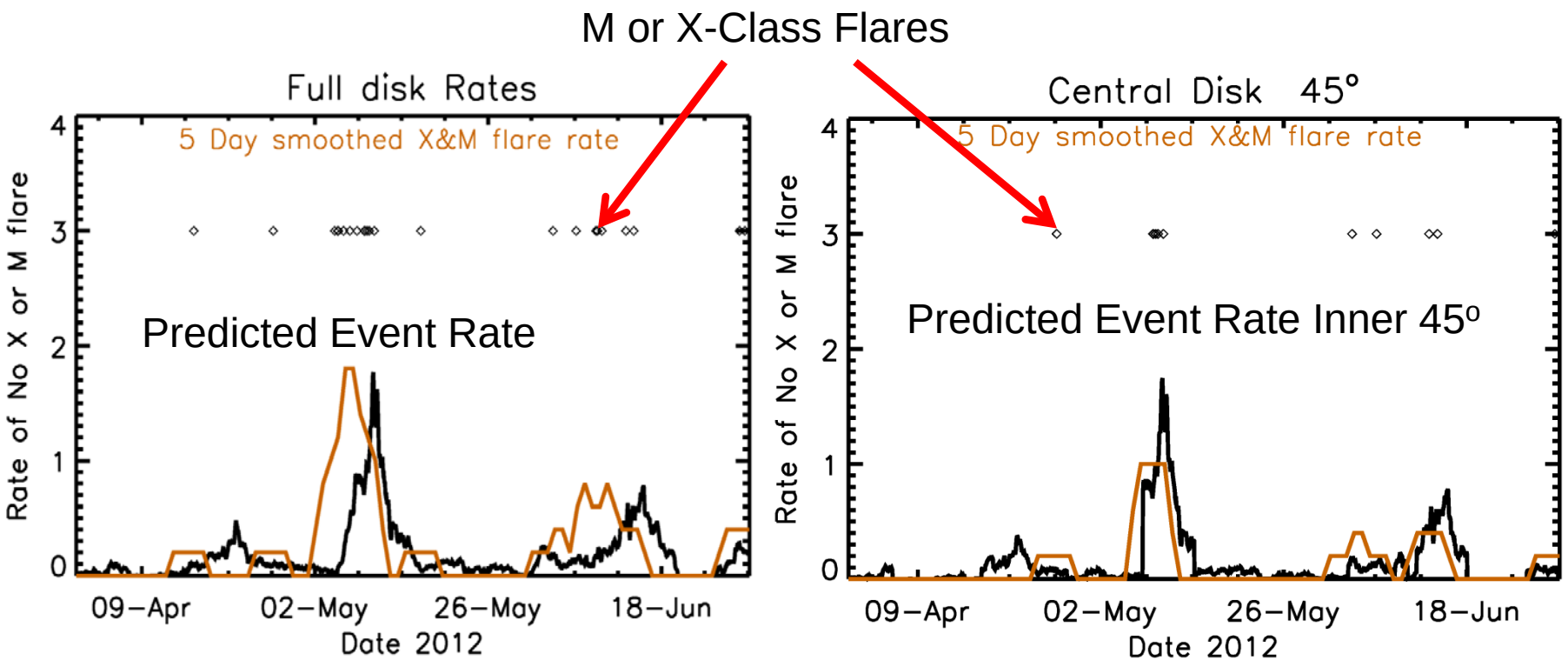




How Well Does MAG4

Situational Awareness

- During periods when flare-productive active regions cross the disk, the predicted rate and actual rate both increase, providing situational awareness
- The results are best when flares and predicted rates are limited to inner 45 degree circle (Right)



Forecast Skill Score

Definitions

	Actual Yes	Actual No
Predict Yes	YY	YN
Predict No	NY	NN

Metric Equations

Percent Correct	PC=(YY+NN)/(YY+YN+NY+YY)
Probability of Detection	POD=YY/(YY+NY)
False Alarm Rate	FAR=YN/(YY+YN)
Heidke Skill Score	HSS=2*(YY*NN-YN*NY)/[(YY+NY)*(NY+NN)+(YY+YN)*(YN+NN)]
True Skill Score	TSS=(YY*NN-NY*YN)/((YY+NY)*(YN+NN))

How Well Does MAG4

Skill Metrics Significance of Upgrade

Forecast Method	YY	YN	NY	NN	PC(%)	POD	FAR	HSS	TSS
McIntosh/**NOAA**	259	638	631	18476	93.7	0.29	0.71	0.26	0.26
Free-Energy Proxy **Present MAG4**	273	284	618	18830	95.5	0.31	0.50	0.35	0.47
Free-energy proxy and previous flare activity **Upgraded MAG4**	340	317	551	18797	**95.7**	**0.38**	**0.48**	**0.42**	**0.49**
Best	890	0	0	19114	100	1	0	1	1

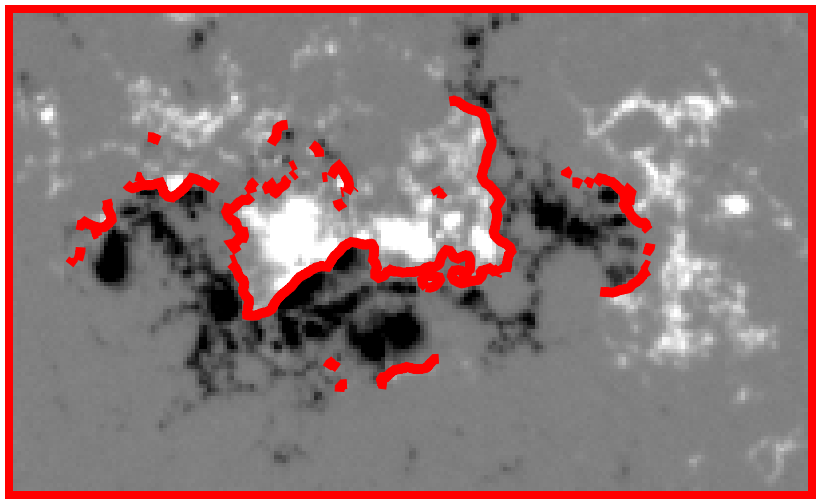
Improvement in Metric	PC(%)	POD	FAR	HSS	TSS
McIntosh/**NOAA** **Present MAG4**	1.8±0.5 **(4σ)**	0.03±0.05 **(0.3σ)**	0.21±0.07 **(3σ)**	0.10±0.04 **(2σ)**	0.21±0.07 **(3σ)**
Present MAG4 **Upgraded MAG4**	0.2±0.2 **(0.7σ)**	0.08±0.03 **(2σ)**	0.02±0.05 **(0.5σ)**	0.06±0.03 **(2σ)**	0.03±0.05 **(0.5σ)**

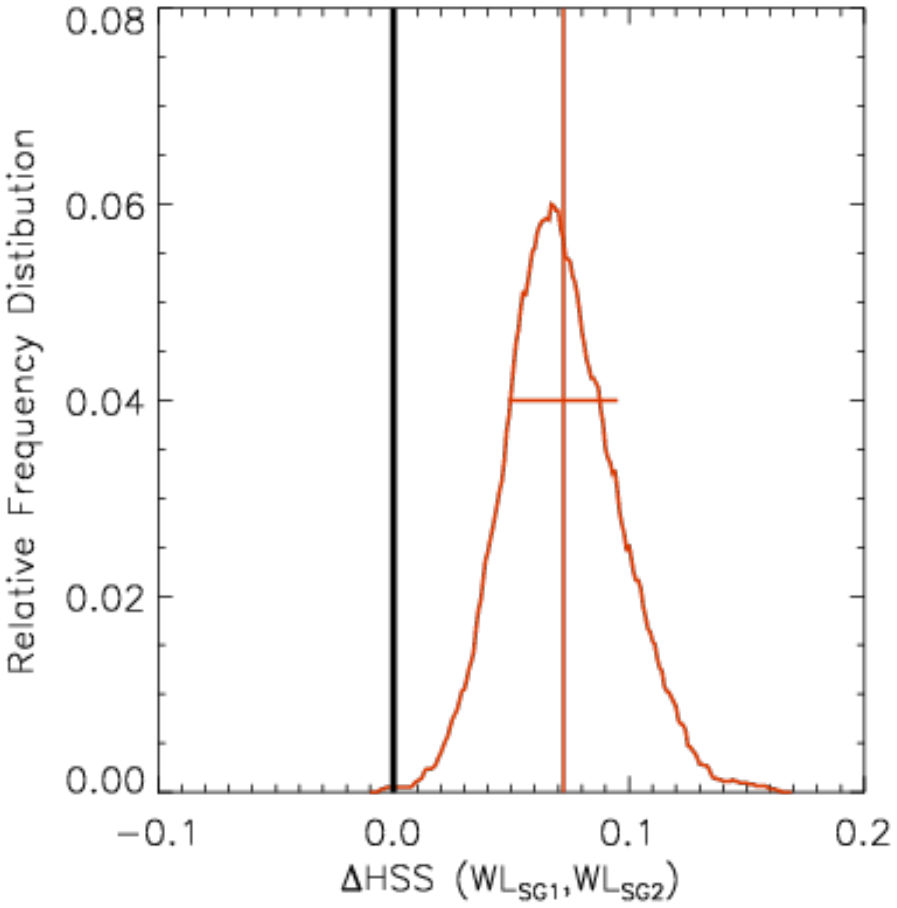
Future Improvement

Free-Energy Proxy

$WL_{SGP}=\int(\nabla B_Z)^P dl$

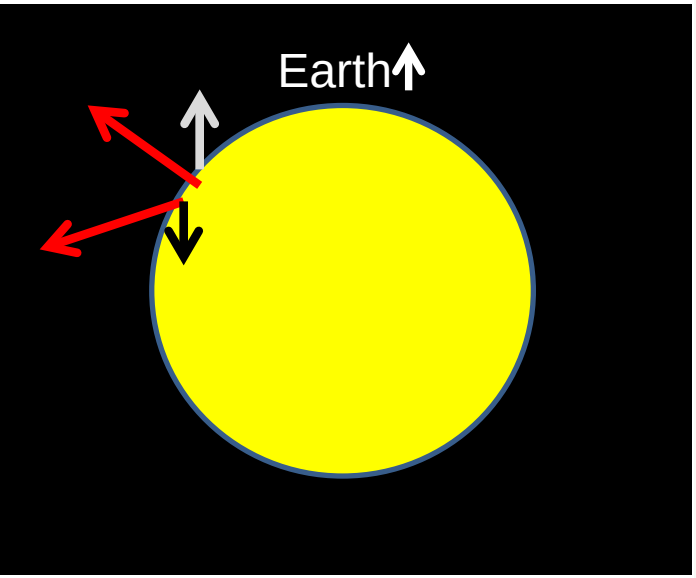
MAG4 presently uses P=1, but we have found at least for M and X-class flares a P of 2-3 is significantly better (~3 sigma).





MAG4 Improvements: Vector Magnetograms

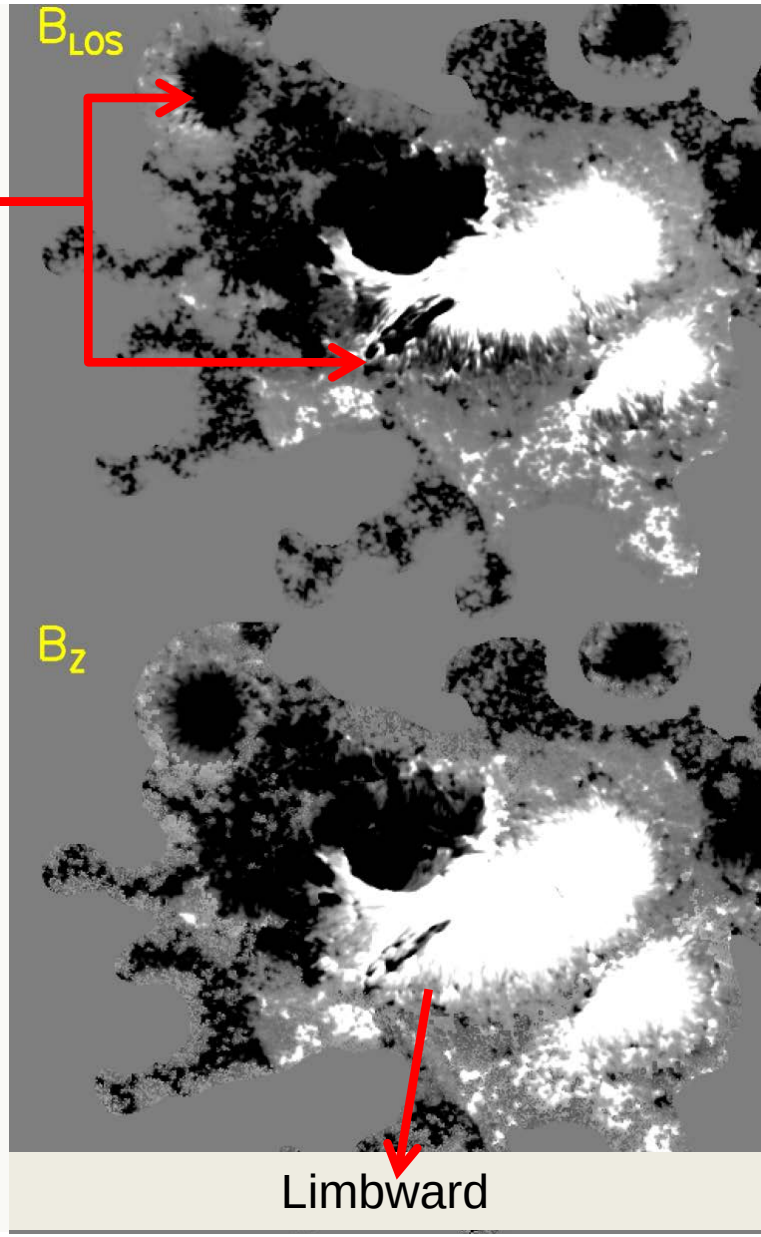
- Both vectors shown in red have positive B_z (magnetic field out of the sun), but have opposite sign B_{LOS} and thus a false (unphysical) neutral line in the line-of-sight (LOS) field.



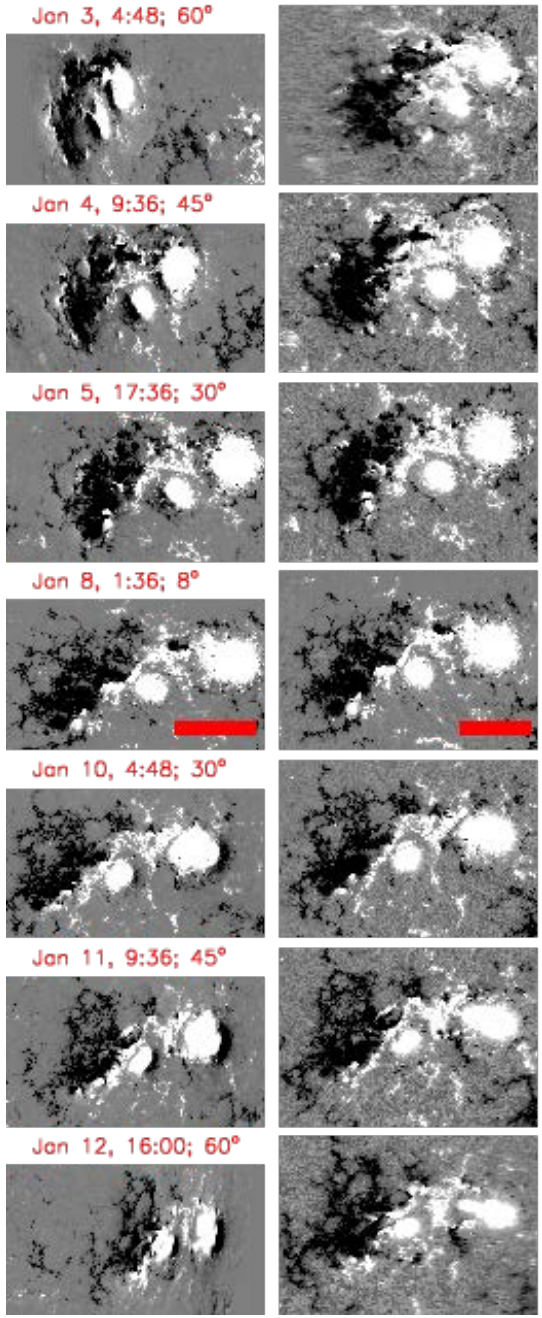
Actual Examples

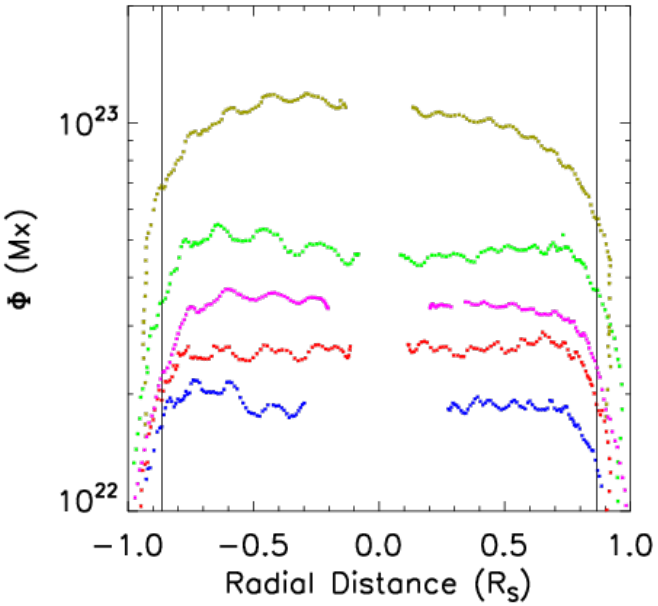
False Neutral Lines occur on limbward sides of sunspots.

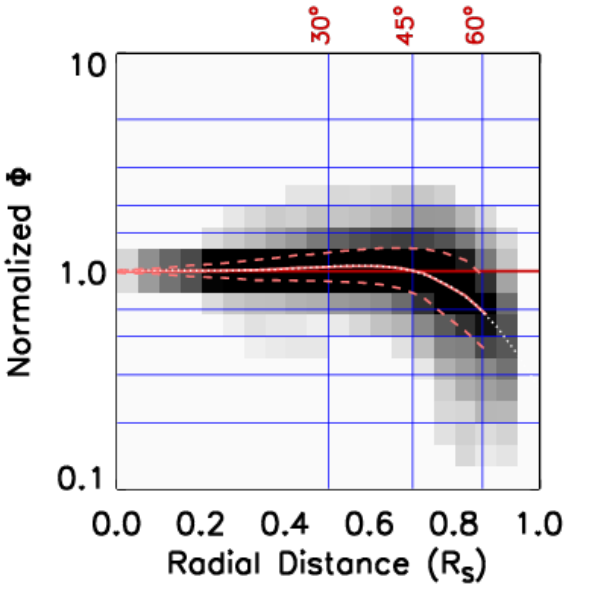
Problem fixed by converting from B_{LOS} and $B_{Transverse}$ to B_Z and $B_{Horizontal}$

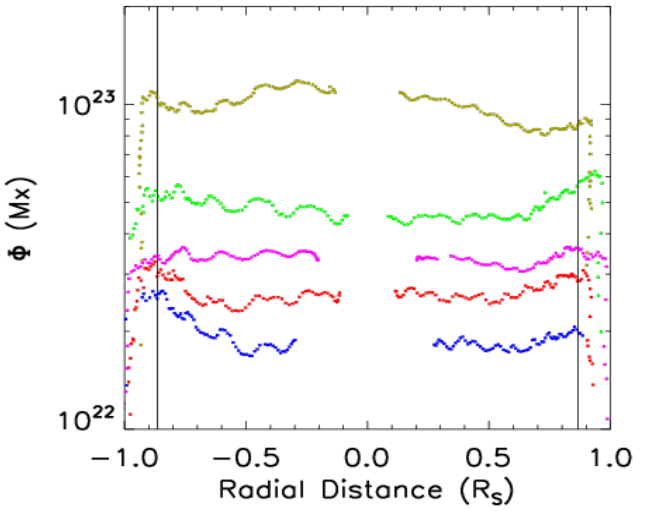


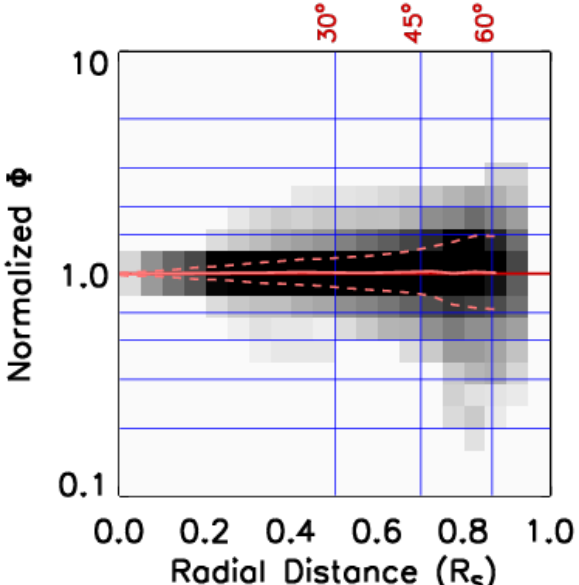
Quantifying and Removing Projection Errors (Falconer et al 2016)











Collaboration

- Sport
- SPRINTS (Thursday 11:40 Alex Engell)
  - We will be training on integrated X-ray flux instead of flare class. See Alex talk.

Conclusions

- MAG4 can give a prediction of probability of major flares and CMEs which are severe drivers of space weather
- The most useful forecast is all clear, that there is little risk from the Sun today
- MAG4 is being improved to give more accurate forecasts
- MAG4 is being used in collaboration, and we are seeking additional collaborations

Backup

MAG4 Research-to-Operations **Timeline**

- *2011* MAG4 installed at JSC Space Radiation Analysis Group (SRAG) as a NRT (Near-Real-Time) forecasting tool, and SRAG began pre-operations testing
- *2012* Provided NOAA web access to MAG4 NRT forecasts
- *2013* MAG4 upgraded so that it can use a combination **of free-energy proxy** and previous **flare activity, for better accuracy**
- *2013* Won the Silver Snoopy Award
- *2015* Transition from HMI line-of-sight magnetogram to vector magnetograms
- *2016* MSFC Software of the Year Award, Honorable Mention for NASA's

Silver Snoopy

"Employees must have significantly contributed to the human space flight program to ensure flight safety and mission success."

Dangerous Time Periods Exist

Actual operational data from JSC/SRAG